Purdue University
Purdue e-Pubs

LARS Symposia

Laboratory for Applications of Remote Sensing

1-1-1975

Machine Aided Multispectral Analysis Utilizing Skylab Thermal Data for Land Use Mapping

L. L. Biehl

L. F. Silva

Reprinted from

Symposium on
Machine Processing of
Remotely Sensed Data

June 3 - 5, 1975

The Laboratory for Applications of
Remote Sensing

Purdue University
West Lafayette
Indiana

IEEE Catalog No.
75CH1009-0 -C

Machine Aided Multispectral Analysis Utilizing Skylab Thermal Data for Land Use Mapping*

L. L. Biehl and L. F. Silva

Purdue University, West Lafayette, IN

I. Abstract

Eight channel Skylab multispectral scanner data obtained in January, 1974, was used in a level two land-use analysis of Allen County, Indiana. The data set which includes one visible channel, four near infrared channels, two middle infrared channels, and one far infrared channel was from the X-5 detector array of the S-192 experiment in the Earth Resources Experiment Package on board the Skylab space station. The results indicate that a good quality far infrared (thermal) channel is very valuable for land use mapping during the winter months.

II Introduction

Land use studies using winter time spacecraft multispectral scanner (MSS) data with only reflective channels [visible (VIS), near infrared (NIR), and middle infrared (MIR)] avaliable, .4μm to 2.5 μm, have been difficult because of the lack of contrast between land use classes. Residential housing, commercial areas, bare or fallow agricultural land, and deciduous wooded areas, are more easily separated during the summer months because each use is characterized by varying combinations of green vegetation and man made features. During the winter months, the reflected energy from .6 hectare (1.5 acres) of residential areas, agriculture areas, and commercial-industrial areas is very similar in the reflective portion of the electromagnetic spectrum, since little green vegetation is present (i.e. dormant vegetation predominants). (The resolution of the present Landsat and Skylab scanners is approximately 0.6 hectare).

The purpose of this study was to investigate the usefulness of a spacecraft MSS data set which included a thermal (far infrared) channel in addition to reflective channels in a land use analysis of a scene obtained during January, 1974. The specific test site was a rectangular area in Indiana which includes Allen County and a small portion of Whitley County. This includes the City of Fort Wayne with a population of around 180,000. Unfortunately, no data was available for approximately 8,900 hectares (22,000 acres) in the southeast portion of Allen County.

Eight channel multispectral scanner data (S-192 experiment) and photography (S-190A experiment) from the Skylab Earth Resources Experiment Package (EREP) was obtained over northeastern Indiana from Lake Michigan to the Ohio-Indiana border on January 25, 1974 at approximately 17:00 GMT (12:00 noon local time). The spacecraft was at an altitude of 440 km. (270 statute miles). The multispectral scanner data included one VIS channel, four NIR channels, two MIR channels and one FIR or thermal (T) channel. (See Table 1). The specifications of the S-190A and S-192 experiments have been reported previously (A. E. Potter et al, 1974).

This detector arrangement for the

* This work was supported by NASA under Contract NAS 9-13301

however, were not separable from the dark bare land class.

After the eight dimensional Gaussian statistics (mean vectors and covariance matrices) were obtained for the twelve spectral classes, the transformed divergence distance measure (Swain, 1972) was used to obtain a measure of separability of the land use classes using different combinations of spectral channels. Transformed divergence behaves similar to the probability of correct classification (Swain, 1972).

Tables 5, 6, and 7 contain the separability information for the best ten combinations of three, four, and five channel combinations respectively, ranked according to the D(ave) - the average of 62 pairwise class combinations. Transformed divergence is only a measure of separability between two classes. The average of all pairwise combinations can be used to extend the separability measure to a multiclass case. D(min) is the minimum separability of the 62 pairwise combinations. The maximum separability measure is 2,000, since transformed divergence is a saturating divergence measure.

Three different combinations of four channels were used to classify the test area--the best four channels (4,8,11,13), the best four without the FIR channel (4,7,8,11) and the best four without a MIR channel (1,8,9,11). The "best" mentioned above was selected according to highest D(ave). The Bayes maximum likelihood classification rule was used in the classification process. Weights or <u>a priori</u> probabilities of occurance for each class were calculated using the statistics given in the Indiana Soil and Water Conservation Needs Inventory. These statistics were gathered in 1967. The classification maps are shown in Figures 1,2, and 3. The acreage estimates of the classes for the three classification sets along with the estimates given in the 1968 Soil and Water Conservation Needs Inventory for Allen County are given in Table 8.

The acreage estimates were found using a conversion factor of one pixel equaling .5 hectares (1.245 acres). The conversion factor was found by scaling the data with the actual distance represented. Each pixel represents approximately 69 m (227 ft.) by 73 m. (238 ft.) (north-south by east-west).

IV. Discussion of Results

The data quality measures (Table 2) indicate that the MIR and FIR channels are the best, the NIR channels next best and the VIS channel the worst, considering the smallest standard deviation to represent least noise in the data. The standard deviation for the FIR channel (2.5) represents approximately 1.2°C. The best four channels considering data quality were not selected as the best four channels considering information content (separability). However, within the NIR and MIR regions, the channels with the least noise tended to be selected over the "noisier" channels according to the noise measure used (Table 2) and the separability tables. (Tables 5, 6, and 7).

The FIR channel could distinguish the areas with buildings from the cooler undeveloped land, as indicated in Table 3 and Figure 4. The temperatures of the grass and residential areas overlapped some but the grass exhibited much higher reflectance in the NIR channels than did the residential areas. The industrial centers in Allen County were very distinguishable from their surroundings in the FIR channel; they were much warmer. In the channels (4, 8, 11, 13) classification, school buildings (such as Ft. Wayne Northrop) were classified as industrial. The school buildings are built similar to the factories with large areas of flat tarred roofs. The higher thermal energy being radiated from these buildings is probably due to a combination of the building heat loss and the high solar absorbtion of the black tar roofs. This is speculated to be the same reason for the residentials areas being warmer than the undeveloped land. However, since the houses are smaller than the factories and school buildings, residential areas are cooler than the industrial centers and schools.

The surface of grass covered areas is generally warmer than bare land. The grass blades act similar to a black body, absorbing the solar energy from the sun. The grass blades insulate the ground beneath which acts similar to a large heat sink in areas with no cover. Therefore, the surface of the grass is warmer than bare land.

The different temperatures for the three bare land classes is probably due to the differing soil types and crop stubble cover. The dark ground in the Lake Maumee Plain west of Fort Wayne and the old glacial river bed (Little River) east of Fort Wayne was the coolest.

The separability information given in Table 6 for the best four channel combinations indicate that the FIR channel

Skylab MSS is termed the X-5 detector array. A new FIR detector was installed midway through the Skylab IV (SL-4) mission. When the new detector was installed, the number of spectral channels was reduced from the original thirteen to eight. The new FIR detector, however, had a noise equivalent temperature (NEΔT) of approximately .9°C compared with the previous detector of 2.2°C-4.5°C (Martin Marietta Corporation, 1974).

Supporting underflight MSS data and photography was obtained five days later over Fort Wayne on January 30, 1974 by an aircraft operated by the Environmental Research Institute of Michigan (ERIM) from an altitude of 2,300 m. These data were used for ground reference during analysis of the Skylab MSS data.

At the time of the Skylab overpass there was some snow on the ground in the northern part of the county--mainly along fence rows and woods. During the week before the overpass, 1.4 inches of rain was reported by the Fort Wayne Disposal Plant (NOAA, 1974). There was some lowland flooding along the Maumee and St. Mary's Rivers at the time of the overpass. The high and low temperatures reported by the National Weather Service at Baer Field for the day of the overpass was 6.7°C (44°F) and -2.8°C (27°F) respectively (NOAA, 1974). The sun angle at the time of the overpass was 30 degrees.

III Analysis Procedure

During the early analysis of the MSS data, it was discovered that channels eight and thirteen (see Table 1) were misregistered by one pixel. The misregistration was corrected by the Data Processing Group at LARS, but the authors, at this time, do not know how the misregistration occurred. After the MSS data was registered, the Data Processing Group, using programs they have developed, rotated the data so that the top of the MSS data is due north. The top of the original data is northwest because of the orbital inclination angle of the Skylab space station.

A measure of the noise in each channel of the MSS data was obtained by computing the mean and standard deviation of five areas of Lake Michigan each totaling 250 points , similar to the method used previously by the authors (Biehl and Silva, 1975). Lake Michigan was chosen because it was the most uniform spectral scene in the data set. The results are given in Table 2.

An attempt was made to "calibrate" the FIR channel by converting the data counts of the FIR channel to degrees centigrade. The procedure consisted of converting the data count to radiance (R), using A_0, E_0, A_1 and E_1 given in the original tape header record and equation one (Philco-Ford Corporation, 1973).

$$R=A_0 \cdot 10\exp(E_0)+A_1 \cdot 10\exp(E_1) \cdot (\text{data count}) \quad 1$$

The radiance (R) was then converted to temperature in degrees Kelvin using the table given in the Skylab S-192 data calibration documentation (Instrumentation Integration Branch, 1974). The table was produced by integrating over the actual bandpass of the FIR detector. A weak point in this procedure is that the table for converting radiance to degrees Kelvin was developed using the bandpass of the original FIR detector, not the new detector for the X-5 array that was installed midway through the SL-4 mission. The actual bandpass information for the new detector was not available. The detectors are supposed to be similar so that any difference should not affect the table significantly. The correlation of the FIR channel data count and degrees centigrade for the training statistics used to represent the twelve spectral classes are given in Table 3. It should be noted that no correction has been made for atmospheric attenuation.

The pattern recognition programs that have been implemented on the computer at LARS in a software package called LARSYS (Phillips, 1973) were used in a level two classification of the test area. The level two classification corresponded to the land use classes suggested by Anderson et al. (Anderson et al, 1972).

Areas of the test site were clustered and then, using the support photography from the Michigan aircraft, training areas were selected for residential, commercial, industrial, "stone" (parking lots and runways), grass covered areas, bare land, forest, water, and snow classes. See Table 4 for the level one and level two break down of the land use classes. Grass includes some pastures, wheat, and golf courses. There were also three spectral classes of bare land, probably due to tilled land, different soil types, and/or land with crop stubble. There were two spectral classes for forest also-that with snow among the trees and that without snow. The wooded areas without snow, is relatively important for separating the spectral classes being used for this study. The FIR channel is selected in every one of the top ten combinations; in fact, it was selected in the top 21 combinations. Channels 4,7,8,11 were the 22nd combination with a D(ave) of 1895 and D(min) of 772. The low class combination was industrial and bare land. Other class combinations with a separability less than 1500 were residential - bare land and commercial-industrial.

The FIR channel is selected eight times in the top ten combinations of three channels. (See Table 5). However, there is always at least one pair of classes that will be hard to separate with any combination of three channels. Generally, any class combination with a separability measure less than 1500 will be hard to separate. According to the separability measures, at least four channels are need to obtain a good class separation in a classification of the study site.

The FIR channel is selected in all of the top ten combinations of five channels (Table 7). It is actually chosen in the top 29 combinations of five channels. (32 possible combinations of channels exist that include the FIR channel).

The MIR region of the spectrum also appears to be important in the separation of the classes for this study in that a channel from that region is selected in the top ten separability combinations using both four channels and five channels. The highest four channel combination that does not include a MIR channel (4,8,9,13) is ranked 14th. The 4,8,9,13 combination has a D(ave) of 1907 and a D(min) of 744. The pair of classes having the minimum separability is grass and one of the bare land classes.

Another observation from Table 6 is that a VIS, NIR, MIR, FIR combination occurs seven times in the top ten combinations. There are eight possible combinations of VIS, NIR, MIR, FIR. This same phenomenon also occurs in tables 5 and 7. The channel combinations which give the best separability for the classes considered tend to be those that have as many of the four spectral regions as possible represented. In the top ten combinations of the three channels, none of the four spectral regions is represented twice. In the top ten combinations of five channels every region is represented at least once.

One can see from the classification maps of Allen County (Figures 1,2, and 3) that the urban and agriculture classes are much more mixed and scattered in the 4,7,8,11 classification (no FIR) than in the 4,8,11,13 classification (with FIR). Some of the rivers and bare land was classified as residential in the 4,7,8,11 classification (no thermal).

The differences in the 4,8,11,13 classification and the 4,8,9,13 classification (no MIR) are not as great as those between the FIR and no FIR classifications. The 4,8,9,13 classification didn't delineate the grassy areas as well as 4,8,11, 13. There was also more confusion between bare land and water in the 4,8,9,13 classification. The 4,8,9,13 classification doesn't display the three rivers (St. Mary's, St. Joseph's and Maumee) as well as 4,8,11,13 classification. Also there appears to be more agriculture land in the city of Fort Wayne in the 4,8,9, 13 classification than in the 4,8,11,13 classification.

The results in Table 8 indicate that nearly three or four times as much area in the classification without the FIR channel was classified as urban than in the classifications with a FIR channel. The 4, 8, 11, 13 classification is probably the most representative of the area with approximately ten percent classified as urban. This urban figure doesn't include the areas in Allen County which are usually considered part of the urban area but are not represented by buildings as parks, golf courses, and railroads. These areas were either classified as grass or bare land. Therefore, the urban figure from the classifications is expected to be lower than that given in the Soil & Water Conservation Needs Inventory (SCNI). Also, the areas represented by the classifications sets are not the exact area represented by the SCNI figures.

The acreage of forest in the classification sets is lower than that given in the SCNI data because of the inability to separate the wooded areas without snow from bare land areas. The water figure in the SCNI data includes only small bodies of water less than forty acres. The water figure in the classifications include the rivers and the areas which were flooded.

More extensive comparisons of the acreage estimates is being planned with more recent and detailed data from the Allen County Plan Commission but the task hasn't been completed at the time of writing this paper.

V. Conclusions

The study indicates that a FIR channel with a detectivity and a responsivity of that in the X-5 detector array can be very valuable for winter time land use studies with spacecraft multispectral data. The FIR channel can distinguish the areas with man made buildings from the cooler undeveloped land. The FIR channel can also distinguish different urban classes. The commercial and industrial areas are warmer than the residential areas. As mentioned before, it is speculated that the urban areas are warmer than the undeveloped land because of a combination of building heat losses and high solar absorption by the asphalt roofs.

A MIR channel also appears helpful in delineating the classes considered. In fact the results indicate that for the channels available in this data set, at least one channel is needed from each of the following spectral regions - VIS, NIR, MIR, and FIR to most effectively separate the land use classes considered in this study.

Future consideration for land use studies using spacecraft multispectral data should include temporal data sets with FIR channels. A temporal overlay of two multispectral data sets which include a FIR channel, one obtained in the winter months and one obtained in the summer months, may be a very effective data set for land use work. A more complete level two breakdown of the land use classes may be possible.

VI REFERENCES

Anderson, J. R., E. E. Hardy, and J. T. Roach, "A Land-use Classification system for Use with Remote Sensing Data, "U. S. Geological Survey Circular 671, 1972.

Biehl, L. L. and L. F. Silva, "A Multilevel, Multispectral Data Set Analysis in the Visible and Infrared Wavelength Regions," Proc. of the IEEE, vol. 63, no. 1, pp 165-167, January, 1975.

Instrumentation Integration Branch, Test Division, Program Operations Office, "Earth Resources Experiment Package Experiment Calibration Data," MSC-07744 Revision B change 3, pp. 4.6-88, 1974.

Martin Marietta Corporation, "Skylab EREP Sensor Performance Report Volume III (S-192), Engineering Baseline, SL2, SL3, and SL4 Evaluation, MSC-05528, NASA, JSC, Houston, Texas, pp. 9.2-9.3c, 1974.

NOAA, "Climatological Data for Indiana", National Oceanic and Atmospheric Administration, Environmental Data Service, Asheville, N. C. vol. 74, no. 1, January, 1974.

Philco-Ford Corporation, Aerospace and Defense Systems Operations, WDL Division, "Earth Resources Production Processing Requirements for EREP Electronic Sensors," prepared for NASA, JSC, Houston, Texas, PHO-TR524 REV. A, pp. 5-19, May 10, 1973.

Phillips, T. L. Ed. LARSYS Version 3 User's Manual, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, IN, 1973.

Potter, A. E. et. al., "Summary of Flight Performance of the Skylab Earth Resources Experiment Package (EREP)," in Proc. 9th Int. Symp. Remote Sensing of Environment, April, 1974.

Swain, P. H., "Pattern Recognition: A Basis for Remote Sensing Data Analysis", LARS Information Note 111572, Purdue University, West Lafayette, Indiana, 1972.

Table 1

SKYLAB MSS (S192) SPECTRAL BANDWIDTHS

Channel	Spectral Region	Spectral Bandwidths
4	Visible	0.56- 0.61 um
6	Near-infrared	0.68- 0.76
7	Near-infrared	0.78- 0.88
8	Near-infrared	0.98- 1.08
9	Near-infrared	1.09- 1.19
11	Middle-infrared	1.55- 1.75
12	Middle-infrared	2.10- 2.35
13	Far-infrared	10.20-12.50

Table 2

"Data Quality" Measures Obtained from Five Areas at Lake Michigan

(mean of 250 points, standard deviation of 250 points)

Channel	1		2		3		4		5	
4	65.9	25.1	63.2	24.6	56.4	23.7	57.7	25.7	62.3	25.4
6	13.8	10.6	12.4	10.3	12.6	10.7	13.3	10.3	9.6	9.3
7	6.8	6.7	6.3	6.5	5.1	6.4	8.1	7.5	6.3	6.7
8	6.8	7.9	6.7	8.0	6.5	8.8	8.4	9.2	6.8	8.8
9	7.3	10.2	7.1	9.6	6.5	9.3	7.3	9.2	7.3	9.9
11	4.5	4.1	4.3	4.1	4.1	4.1	4.6	4.3	3.4	4.0
12	6.0	5.8	4.8	5.4	4.5	5.4	6.2	6.1	4.7	5.5
13	80.3	2.5	84.4	2.7	85.8	2.4	86.5	2.2	83.6	2.9

Table 3

Correlation of the Mean Far-infrared Channel Data Value (and ± one standard deviation) and Temperature for the Twelve Training Classes.

Class	Data Count -Std. Dev.	Data Count Mean	Data Count +Std. Dev.	Temperature (°C) -Std. Dev.	Temperature (°C) Mean	Temperature (°C) +Std. Dev.
Residential	94.5	97.1	99.7	1.3	2.4	3.6
Commercial	99.1	102.9	106.7	3.3	5.1	6.7
Industrial	109.8	116.4	123.0	8.0	10.8	13.5
"Stone"	88.8	92.2	95.7	-1.5	0.3	1.8
Grass	90.3	93.7	97.2	-0.7	1.0	2.5
Bare Land 1	87.6	91.0	94.4	-2.0	-0.4	1.3
Bare Land 2	85.4	89.3	93.2	-3.0	-1.2	0.7
Bare Land 3	83.7	87.1	90.6	-3.9	-2.2	-0.6
Forest	83.5	86.1	88.6	-4.0	-2.7	-1.5
Water 1	83.3	86.5	89.7	-4.0	-2.4	-1.0
Water 2	73.0	75.6	78.2	-9.1	-7.8	-6.5
Snow	78.1	82.8	87.5	-6.6	-4.3	-2.0

Table 4

Landuse Classes Used for Classification of Test Site.

Level 1	Level 2
Urban	Residential
	Commercial
	Industrial
	"Stone" (parking lots and runways)
Agriculture	Grass
	Bare Land
Forest	Forest
Water	Water
Other	Snow

Table 5

Separability of Classes Using Three Channels*

Channels	D(Ave)	D(Min)
4,11,13	1911	535
4, 8,13	1905	941
8,11,13	1904	385
7,11,13	1903	578
4, 8,11	1895	705
6,11,13	1890	1000
4, 9,13	1888	891
8,12,13	1870	340
4, 7,11	1864	527
9,11,13	1863	321

*Separability measure is transformed divergence; maximum value is 2000.

Table 6

Separability of Classes Using Four Channels*

Channels	D(Ave)	D(Min)
4,8,11,13	1963	1620
4,7,11,13	1954	1533
4,9,11,13	1946	1563
4,8,12,13	1937	1331
6,8,11,13	1930	1221
4,6,11,13	1930	1263
6,7,11,13	1919	1271
4,7,12,13	1919	1234
4,9,12,13	1918	1307
7,8,11,13	1914	589

*Separability measure is transformed divergence; maximum value is 2000.

Table 7

Separability of Classes Using Five Channels*

Channels	D(Ave)	D(Min)
4,7, 8,11,13	1977	1667
4,6, 8,11,13	1974	1652
4,8,11,12,13	1974	1646
4,8, 9,11,13	1974	1636
4,7, 9,11,13	1971	1623
4,7,11,12,13	1966	1546
4,6, 9,11,13	1965	1600
4,6, 7,11,13	1965	1568
4,8,11,12,13	1962	1616
4,8, 9,12,13	1956	1439

*Separability measure is transformed divergence; maximum value is 2000.

Table 8

Acreage Estimates for the three Classification Sets and the Soil and Water Conservation Needs Inventory for Allen County

(in hectares)

Land-Use Classes	Needs Inventory	(4,8,11,13)	(4,7,8,11)	(4,8,9,13)
Urban & Built Up	26,184	16,501	46,298	12,198
Residential		15,169	44,570	11,283
Commercial		239	356	275
Industrial		97	563	77
"Stone"		996	809	563
Agriculture	128,449	133,611	103,774	139,286
Grass		11,825	11,498	5,342
Bare Land		121,786	92,276	133,944
Forest	14,260	9,672	10,194	6,758
Water	526	2,420	2,291	2,647
Other Land	4,119			
Snow		5,261	4,889	6,576
Null (S.E. portion of county)		8,863	8,883	8,863
Total	173,538	176,328	176,329	176,328

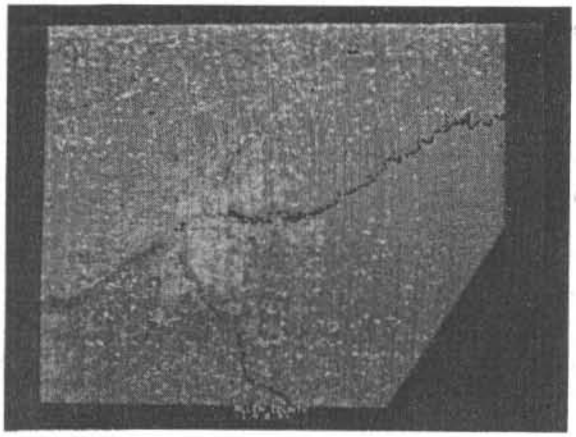

Figure 1. Photo of Classification of Allen County using channels 4,8,11,13. In order of increasing brightness - water, forest, agriculture, urban and snow.

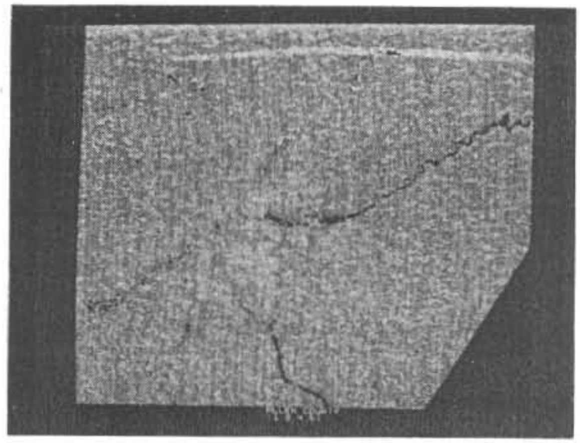

Figure 2. Photo of Classification of Allen County using channels 4,7,8,11 (no FIR). In order of increasing brightness - water, forest, agriculture, urban, and snow.

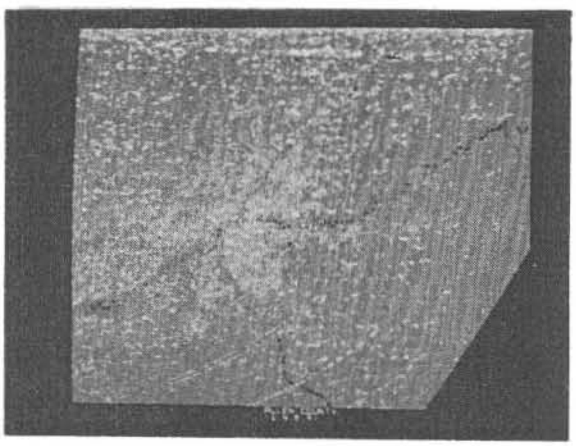

Figure 3. Photo of Classification of Allen County using channels 4,8,9,13 (no MIR). In order of increasing brightness - water, forest, agriculture, urban and snow.

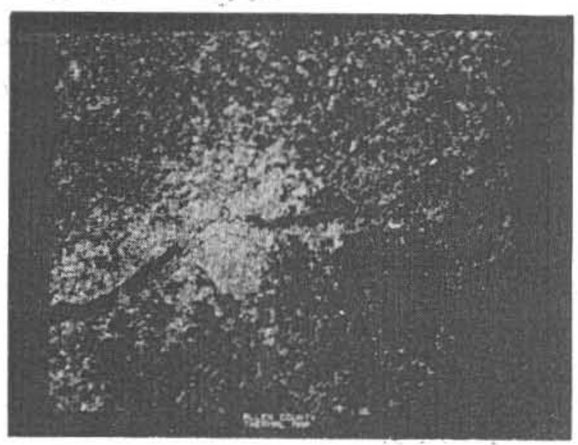

Figure 4. Photo of FIR (thermal) channel imagery over Allen County. Black to white represents coolest to warmest.